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A COMPUTER PROGRAM FOR IDENTIFYING AND MEASURING COMPONENTS IN A MIXTURE OF GAMMA-EMITTING RADIONUCLIDES

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ABSTRACT

A computer program has been developed for the analysis of the components of a gamma pulse-height distribution composed of a mixture of two or more gamma-emitting radicnuclides. The program consists of (1) identifying the largest gamma photopeak and matching its energy with the largest photopeak of each of the individual radionuclides that compose the mixture, (2) subtracting enough of the individual radionuclide gamma pulse-height distribution from the mixture so that the photopeak in question is reduced by a certain small percentage, and (3) continuing the incremental subtraction process until the photopeaks in the mixture can no longer be identified. This computer program has several advantages over other computer programs that have been developed to do the equivalent of a radiochemical analysis on a mixture of radionuclides. It will be especially useful in analyzing the large number of low activity mixtures of radionuclides that are to be made in the program to determine the physical-chemical species of the radionuclide debris produced by underwater nuclear explosions.

SUMMARY

Problem

In a study of the physical and chemical species of radioactive debris resulting from an underwater nuclear explosion, complex mixtures of radionuclides, sometimes of fairly low activity, are to be analyzed. A computer program for resolving the gamma pulse-height distribution of a weakly-active mixture of gamma-emitting radionuclides into its components is required.

Findings

A computer program was developed, and then tested successfully on the gamma pulse-height distribution of a synthetic mixture of 3 radionuclides, each having several photopeaks over a 2 MEV range. The program is based on an iterative subtraction technique and is promising because errors in the analysis were small (0.5 - 2.0 percent), despite the fact that many possible refinements in the program have not yet been made.

INTRODUCTION

This work is part of a program to determine the chemical and physical species of radionuclide debris formed from an underwater nuclear explosion. This underwater nuclear explosion is simulated in the laboratory by exposure of a small bead of uranium metal suspended in seawater to a neutron pulse from a TRIGA reactor. The absorbed neutrons produce enough fissions ($\sim 2 \times 10^{12}$ in 10 mg of U) in a few milliseconds to vaporize the uranium and produce conditions that are similar to those of the actual underwater event.

Study of the long-lived radionuclide debris requires making many separations and identifications on small aliquots of a solution that contains a total of $\sim 2 \times 10^{12}$ fissions in five ml of seawater. Radiochemical separation and identification would be time consuming and difficult to do sequentially (which would be necessary because of the low activity) for several radionuclides in one sample.

A possible alternative to making these difficult radiochemical separations would be to spike the uranium bead before irradiation with relatively large amounts of a carrier-free radionuclide of interest. The assay would consist only of measuring a well-defined gamma

photopeak. However, it would still be necessary to show for each radionuclide that the same results were obtained by both methods, and this would again necessitate solving the above problem of assaying a small amount of a radionuclide from a relatively large amount of radioactivity. In addition, it would be desirable to assay all the radionuclides of interest at one time in order to cut down the total analysis time and to be assured that all the radionuclides underwent the same experimental conditions and could thus be directly intercompared.

A direct solution of this problem was to develop a computer program that would resolve a weakly active sub-mixture of gamma-emitting radionuclides into its components. There are several requirements and conditions to be considered for any computer analysis of the gamma spectra of a sub-mixture of radionuclides: (1) All the major radionuclide components present must be identified, (2) the total amount of activity to be resolved may be very small, (3) the inert matrix containing the radionuclides will be variable.

There are various computer methods presently available for resolving gamma pulse-height distributions. They include spectrum stripping, solution of simultaneous equations, least squares fitting, iterative methods, synthetic methods, and linear programming (some are iterative). A brief outline of each method follows:

(a) Spectrum stripping means identifying the radionuclide with the highest energy peak and then subtracting its normalized pure spectrum from the spectrum of the mixture and repeating this procedure until all components have been identified and quantitated.

(b) Simultaneous equations may be used to solve a spectrum of identified components by dividing the spectrum into regions covering the photopeaks only. Then a set of simultaneous equations is developed relating the counts observed in the channels in the photopeak regions to those measured in a set of standard spectra of the radionuclides.

Within the various channels which constitute the peak the different radionuclides at "unit" composition are known to contribute ST_{ij} counts (i indexes the standard radionuclide, j the channel). In any one channel the counts in the mixture spectrum UNK(j) are given by

$$UNK(j) = \sum a_i \, ST_{ij}$$

or
$$UNK(1) = a_1 \, ST_{11} + a_2 \, ST_{21} + a_3 \, ST_{31} + \ldots\ldots\ldots\ldots a_n \, ST_{n1}$$
$$UNK(2) = a_1 \, ST_{12} + a_2 \, ST_{22} + \ldots\ldots\ldots\ldots\ldots\ldots a_n \, ST_{n2}$$
$$\vdots$$
$$UNK(m) = a_1 \, ST_{1m} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots a_n \, ST_{nm}$$

where the a_i are the unknown composition coefficients of the various radionuclides in the mixture. These sets of simultaneous equations may be solved by straightforward, if tedious, algebra.

(c) Least squares fitting extends the regions considered in b above into every point in the spectrum. This gives as many equations as channels; each equation involves an error term which is minimized in the normal way. That is,

$$\sum_{j=1}^{m} \left(\mathrm{UNK}(j) - \sum_{i=1}^{n} a_i \, ST_{ij} \right)^2$$

is minimized.

(d) Synthetic methods utilize standard spectra to give information regarding such effects as backscatter, X-ray production, β absorption, self-absorption, summation effects and detector performance. For a given energy the method predicts a pulse-height spectrum. This approach can be extended to analysis of a composite spectrum by synthesizing a tried composite spectrum comparing it with the experimental spectrum, and then modifying the synthetic model by iterative procedures until a match is obtained.

(e) Linear programming utilizes the data by requiring a solution of a series of inequalities rather than ordinary simultaneous equations. One method of solution of a set of inequalities (restrictive equations containing slack variables) is called the simplex method. For example instead of

$$a_1 \, ST_{11} + a_2 \, ST_{21} = \mathrm{UNK}(1)$$

we have $a_1 \, ST_{11} + a_2 \, ST_{21} \leq \mathrm{UNK}(1)$

and a slack variable, r_1, is introduced so that

$$a_1 ST_{11} + a_2 ST_{21} + r_1 = UNK(1)$$

These computer methods attempt to give quantitative gamma spectrum analysis. All the techniques are sound mathematically, but the inherent statistical fluctuations in counting lead to difficulties in using methods a, b and c above. Method e is used more where the energy lines of gamma emission are important and the radionuclides are unknown.

The method of computer analysis developed for this program combines some of the features of a and e in order to meet the requirements mentioned above for the type of identification needed in this work.

COMPUTER PROGRAM DESCRIPTION

Briefly, the program works as follows: It identifies the major peak in the gamma pulse-height distribution, compares it with each of the major peaks in a library of pure gamma-emitting radionuclides taken under the same geometry conditions, and subtracts a small fraction of the identified pulse-height distribution from the unknown mixture. The major peak of the resulting pulse-height distribution is identified and the process repeated until no peaks can be identified or unaccounted-for peaks are identified which are not in the library. If necessary these unaccounted-for pulse-height distributions are put into the

library and used to subtract these components from the mixture. The residual counts in the pulse height-distribution are analyzed by a linear programming technique (not yet used in present experiment). This method is particularly suited for pulse-height distributions that have few total counts (less than a thousand) or have poor statistics resulting from the stripping program.

Figure 1 shows a flow diagram of the computer program. Appendix I gives the program in detail. This program represents a very simple straightforward analysis. Many refinements can be added to it as required for practical applications.

EXPERIMENTAL

Several synthetic mixtures were prepared to test the computer program. The first mixture tried was composed of 48.4 % Ti^{44}, 22.1 % Cs^{134}, and 29.5 % Y^{88}. Each of these radionuclides has several gamma photopeaks over a 2 Mev range. The gamma pulse-height distributions of the separate radionuclides and of the mixture were detected with a 3 in. x 3 in. NaI(Tl) crystal and analyzed with a 1024 channel TMC pulse-height analyzer. The computer program was modified to plot the resulting pulse-height distribution after 50 %* of one of the gamma photopeaks was subtracted. Presently the major peak in the mixture is identified and 50 % of this peak and a proportional amount of the rest of the

*These are larger subtractions than would normally be made. Normally only a few percent of the photopeak would be subtracted at each pass. The plots were made after each subtraction in order that trouble that developed could be spotted easily.

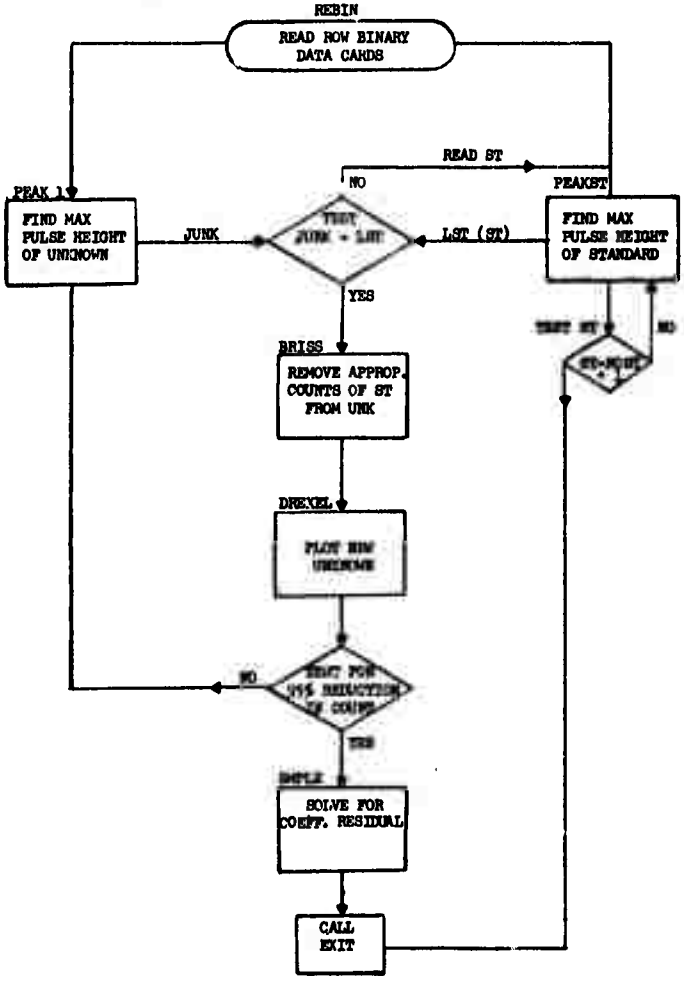


Fig. 1 Flow Diagram for Computer Program Used to Identify Components in a Mixture of Gamma-Emitting Radionuclides.

pulse-height distribution of the radionuclide in the library is subtracted without reading out. This process is then continued until no more peaks can be identified or until a residual pulse-height distribution is obtained that does not belong to the library.

RESULTS AND DISCUSSION

The results of a test of resolving a mixture of the three radionuclides is shown in Table I and Figures 2-12. Pulse-height distributions of the pure radionuclides are shown in Figures 13-15. Each pass represents identification of the largest peak in the mixture and removal of 50 % of the activity in that peak by subtraction of an appropriate amount of the total pulse-height distribution of the pure identified radionuclide in the library. Eleven passes were made, resulting in the removal of 94 % of the total activity. Machine time was 15 minutes.

At each stage the remaining peaks could easily be identified visually and they corresponded with peaks in the library. A test to remove as much activity as possible has not been made yet.

The small errors (0.5 - 2.0 percent) in the analysis are considered very encouraging since many possible refinements to the computer program have not been made. Two of the refinements are concerned with peak identification where two or more peaks are close in energy and with using the simplex method to further resolve the presently remaining residue of the gamma pulse-height distribution.

Table I

Stepwise Subtractions of Radionuclides From a Composite Mixture

Pass	Activity Subtracted at Each Pass (cpm)		
	Ti^{44}	Cs^{134}	Y^{88}
1	66854		
2	32927		
3		35019	
4			41703
5			20852
6		12974	
7	9385		
8			9799
9	4017		
10		5489	
11	1692		
Total counts subtracted	114875	53482	72354
% found	47.7	22.2	30.1
% added	48.4	22.1	29.5
% error	- 1.4	+ 0.5	+ 2.0

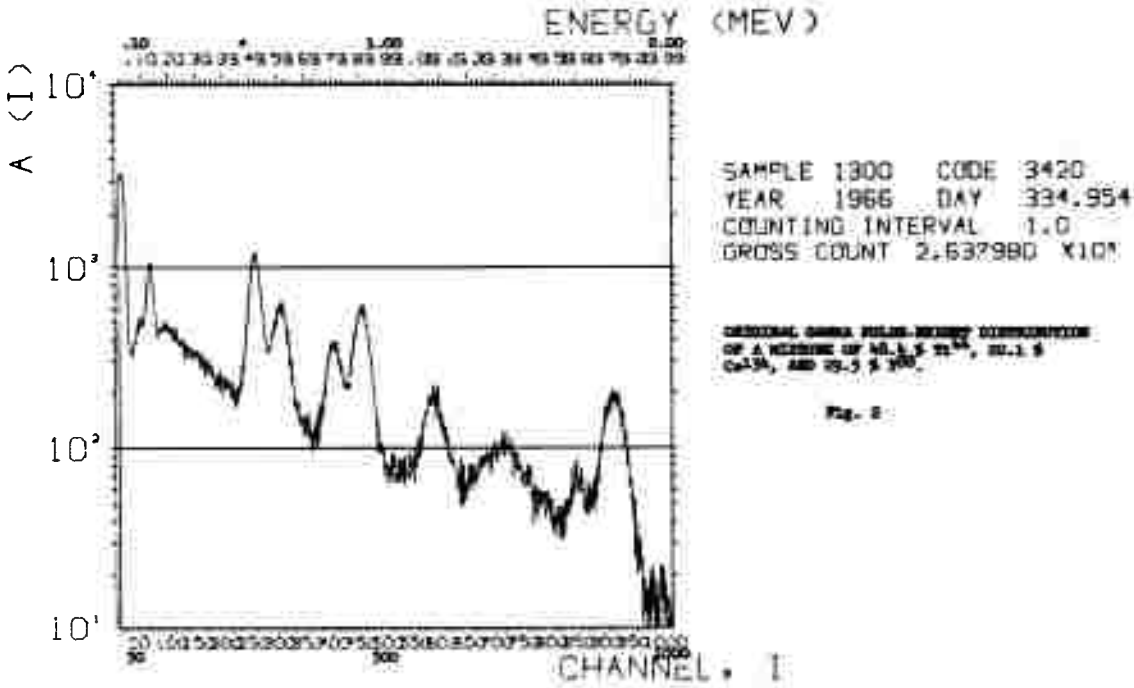
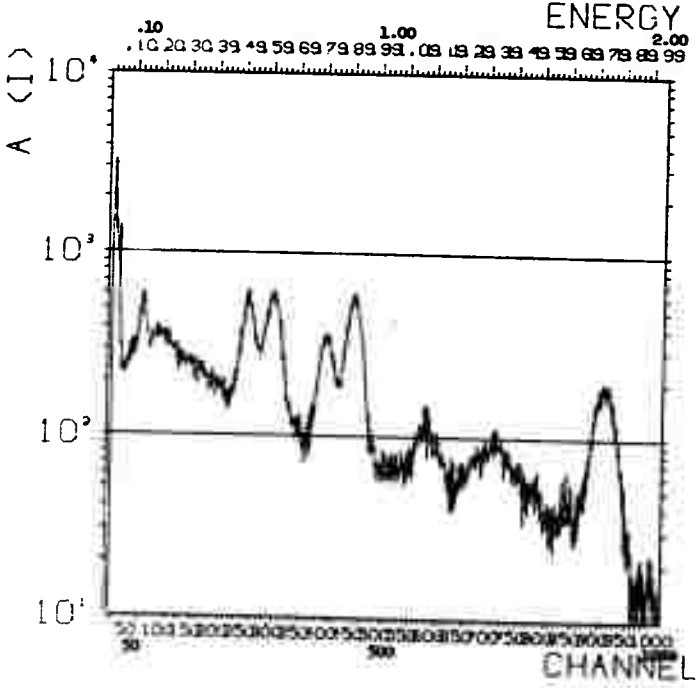

ENERGY (MEV)
A (I)
10^4
10^3
10^2
10^1
CHANNEL, I
SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 2.637980 X10⁵

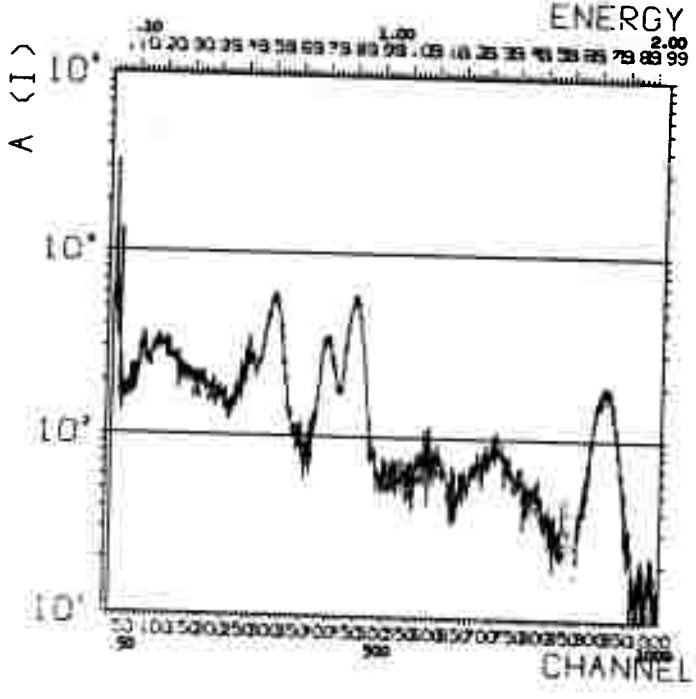
Fig. 8



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 1.979440 X10^5

6.6854×10^4 COUNTS OF Ti-44
SUBTRACTED FROM
2.637980×10^5 COUNT

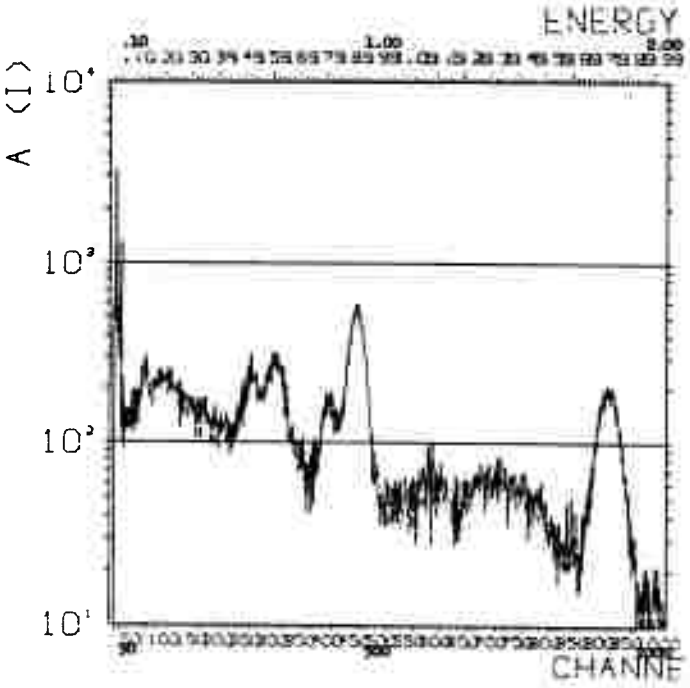
Fig. 3



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 1.650170 X10³

[illegible] COUNTS OF 21.44
ESTIMATED FROM
[illegible] COUNT

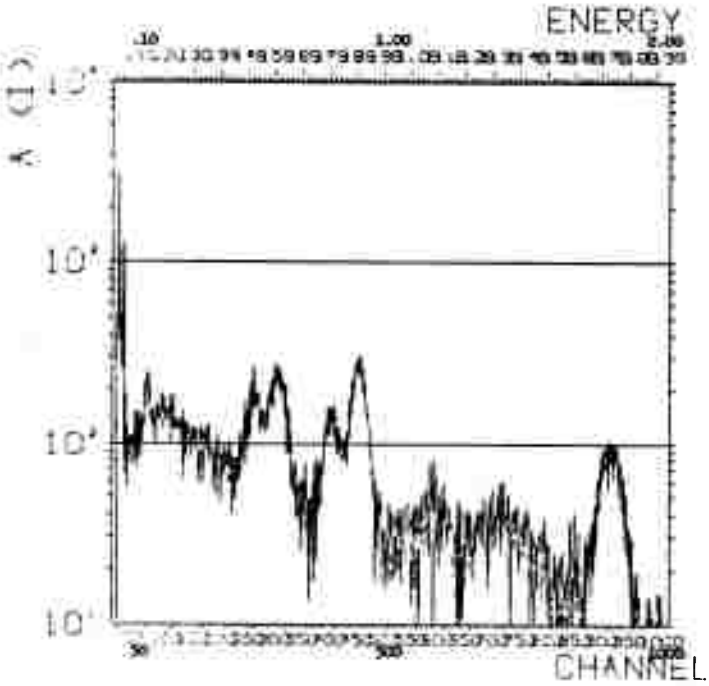
Fig. 4



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 1.299980 X10^5

3.5019 COUNTS OF Cs-134
SUBTRACTED FROM
1.650173 x 10^5 COUNT

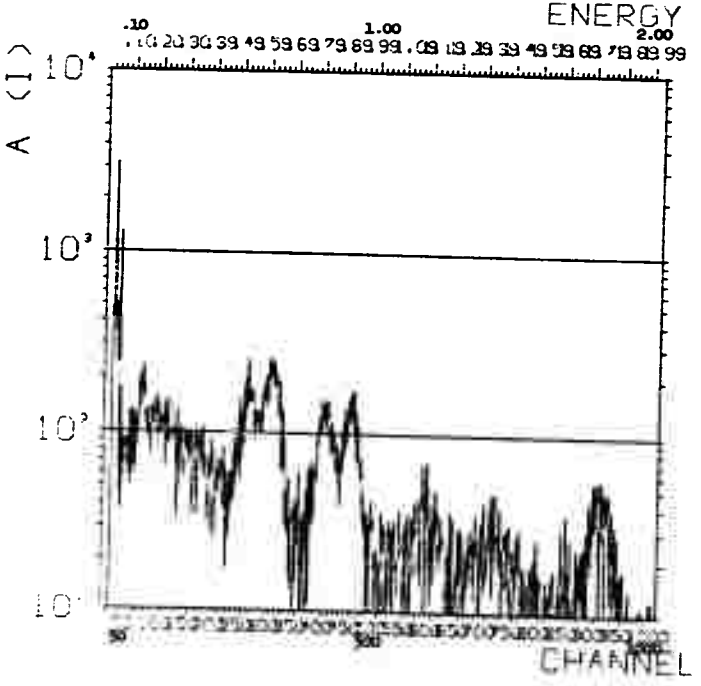
Fig. 5



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 8.829530 X10⁴

[illegible] x 10⁴ counts or [illegible]
subtracted from
[illegible] x 10⁵ count

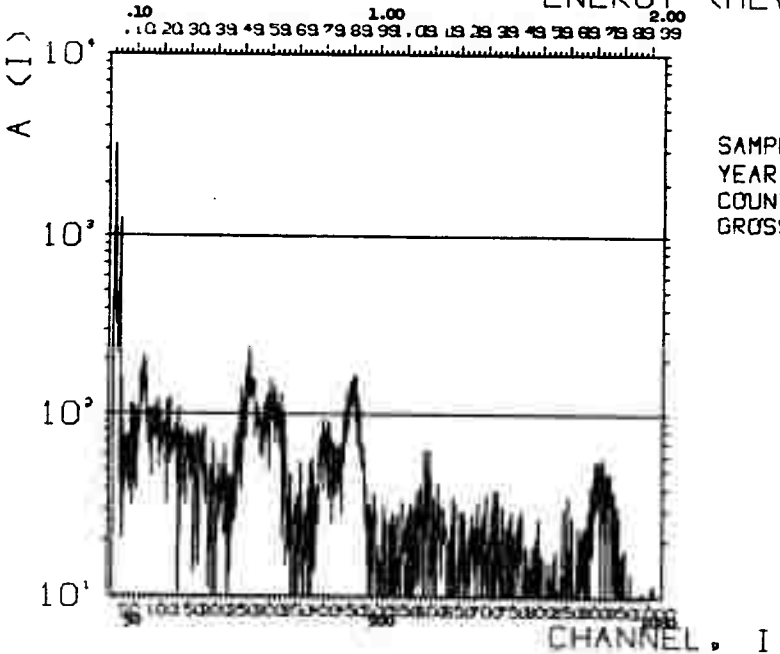
Fig. 6



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 6.744370 X10^4

[illegible] $\times 10^4$ COUNTS OF I-131
[illegible]
[illegible] $\times 10^4$ COUNTS

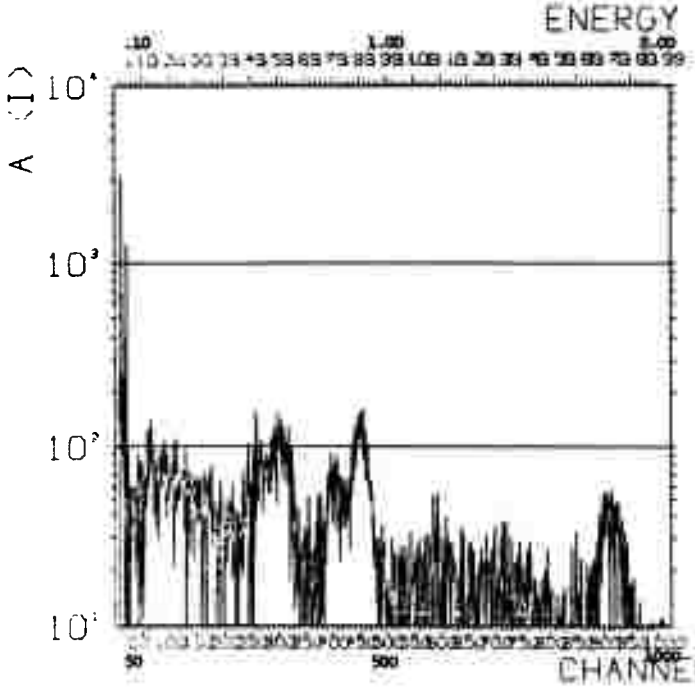
Fig. 7



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 5.447010 X10⁴

1.2974×10^4 COUNTS OF Cs-134
SUBTRACTED FROM
6.744370×10^4 COUNTS

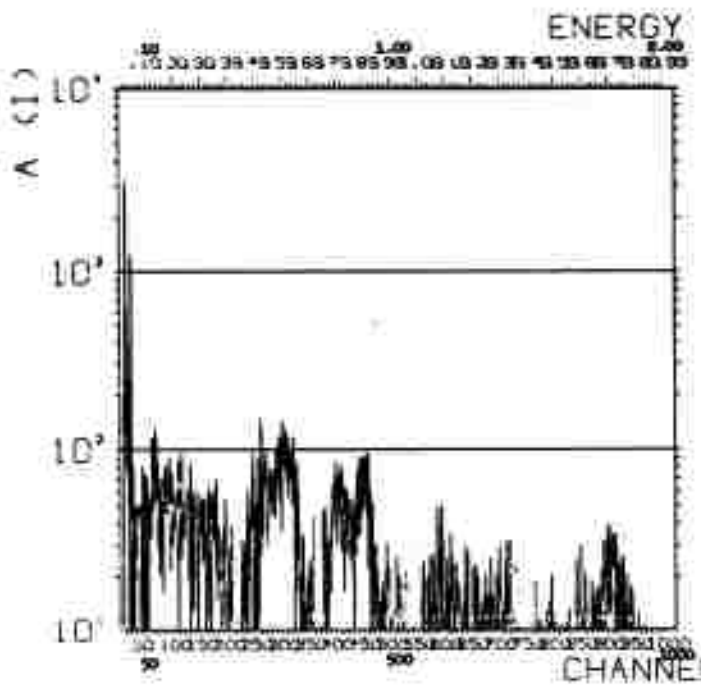
Fig. 8



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 4.508*80 X10*

[illegible] counts of [illegible]
extracted from
[illegible] counts

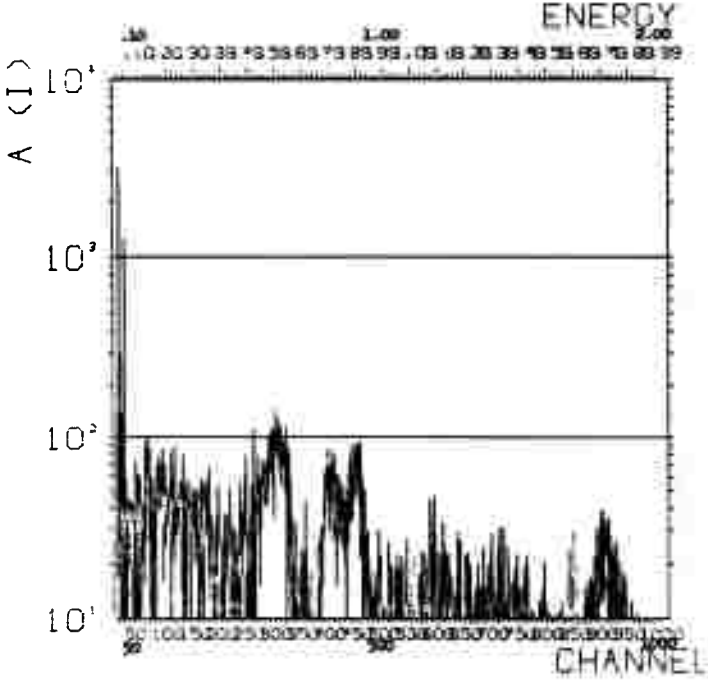
Fig. 9



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 3.528550 X10⁴

9.799×10^3 COUNTS OF Y-88
SUBTRACTED FROM
4.508480×10^4 COUNTS

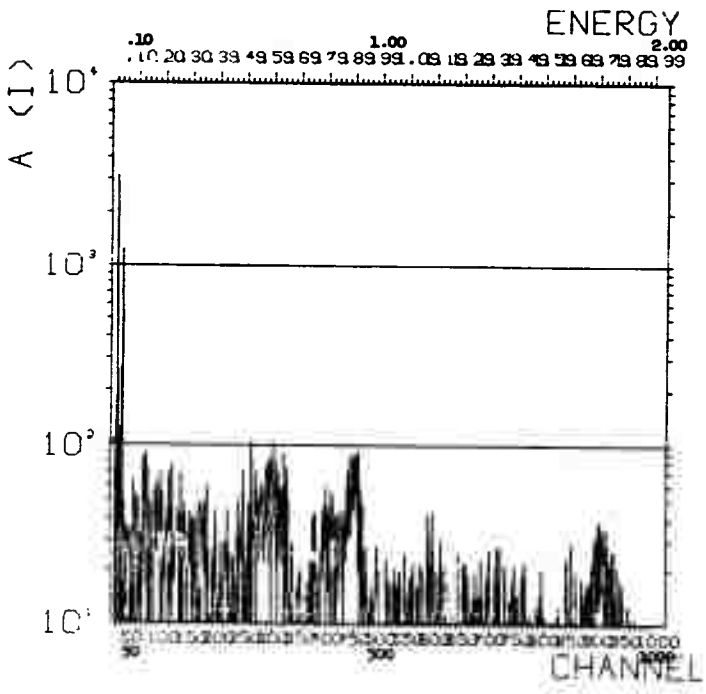
Fig. 10



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.854
COUNTING INTERVAL 1.0
GROSS COUNT 3.126870 X10⁴

4.017 x 10³ COUNTS OF Zr-Nb
REMOVED FROM
3.126870 x 10⁴ COUNTS

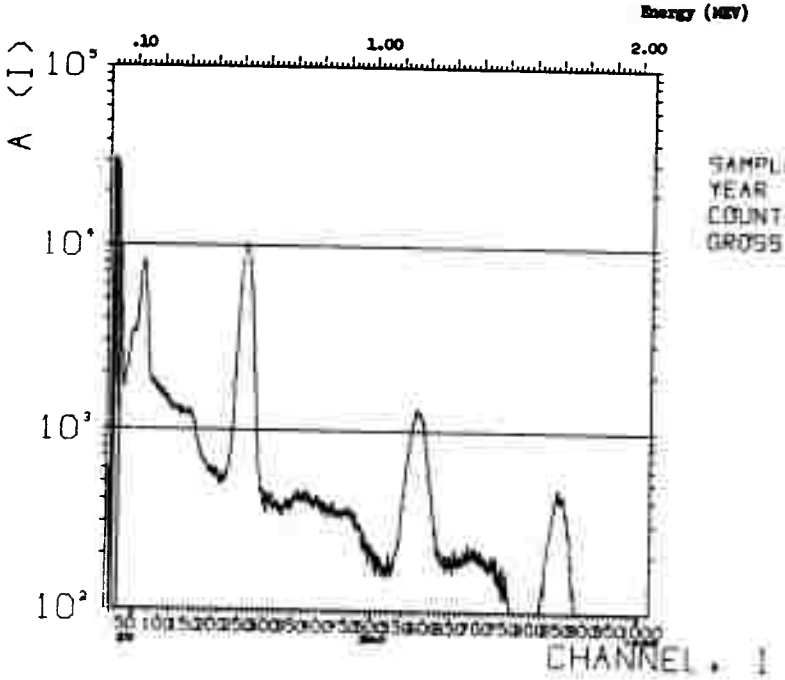
Fig. 11



SAMPLE 1300 CODE 3420
YEAR 1966 DAY 334.954
COUNTING INTERVAL 1.0
GROSS COUNT 2.577980 X10^4

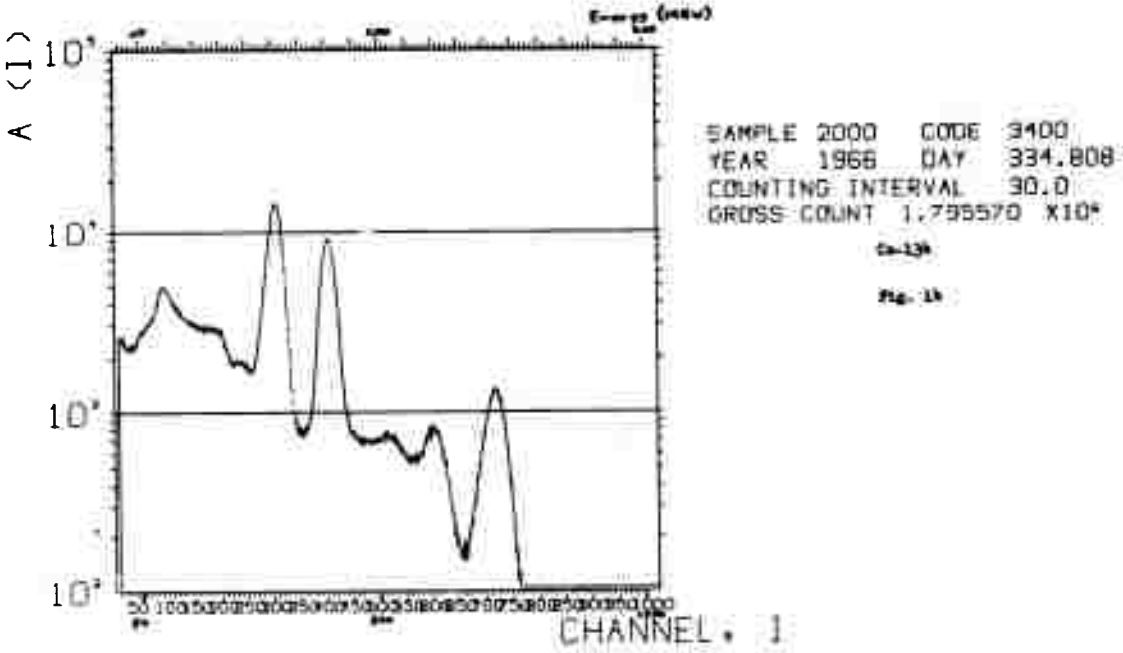
3.489 x 10^3 counts of Cs-134
extracted from
3.106870 x 10^4 counts

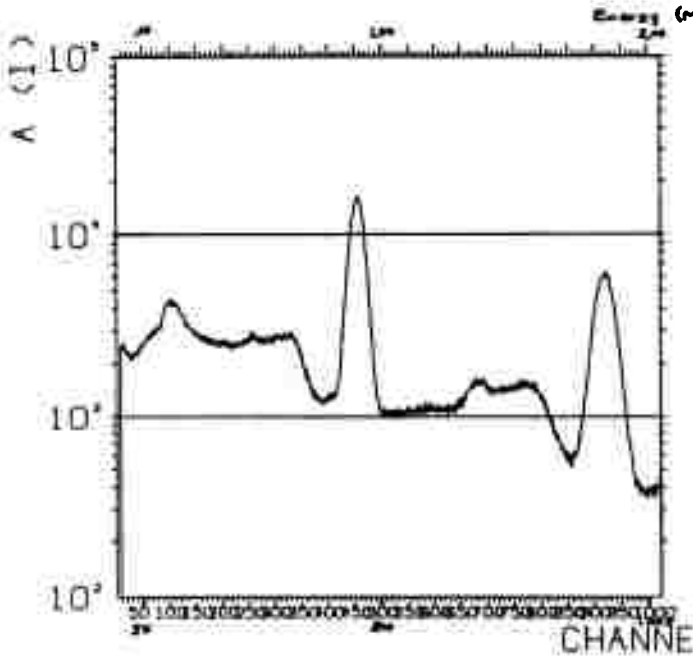
Fig. 12



SAMPLE 1000 CODE 3400
YEAR 1966 DAY 334.782
COUNTING INTERVAL 10.0
GROSS COUNT 1.167210 X10^6

Fig. 13


A (1)
10⁴
10³
10²
10¹
CHANNEL. 1
SAMPLE 2000 CODE 3400
YEAR 1966 DAY 334.808
COUNTING INTERVAL 30.0
GROSS COUNT 1.795570 X10⁴



SAMPLE 3000 CODE 3400
YEAR 1966 DAY 334.838
COUNTING INTERVAL 30.0
GROSS COUNT 2.395550 X10⁶

I-88

Fig. 15

It appears that this technique offers several advantages over other computer methods that have been reported:

(1) The high and low energy portions of the pulse-height distribution do not have to be included if the major peaks are not in these areas. The low energy portion is very sensitive to shifts in energy and is the most complicated part of the spectrum, while the high energy portion often contains only minor fractions of the gamma emitters (that must be included in the usual stripping techniques). Therefore, the range of energies can be quite small, if desired, and the detector gain can be set so that the highest energy peak will determine the upper gain setting and thus maximize the resolution of the detector for the gamma photopeaks.

(2) This computer program for gamma-ray analysis is very sensitive to pulse-height distributions with very small numbers of counts. The only limiting factor in the program is whether a peak can be identified. Peak identification is determined by whether the total counts in an energy span (corresponding to a peak) are greater than the total counts in any other energy span (that might be due to perhaps one or more high statistical fluctuations). Even large statistical fluctuations can be controlled to a great extent by arbitrarily limiting the count ratio of neighboring channels to less than a certain maximum factor such as would occur at the inflection point on the high energy side of a gamma photopeak. Tests are being made for mixtures containing less than 10^3 total counts.

(3) Although it is required to have in the library all the radionuclides in the mixture to get maximum sensitivity, a decided advantage does exist in being able to identify the residue pulse-height distribution which could be due to one or more unexpected radionuclides. With accurate knowledge from the literature of one or more of their gamma photopeaks, identification should be easy. If such a radionuclide is easily produced, its spectrum may be added to the library, and if it is not easily produced its pulse-height distribution can be accurately synthesized from its known decay scheme.

(4) Since only a portion of the pulse-height distribution of the mixture is removed at each pass, the true percentage of each radionuclide present is approached asymptotically. This means that if minor components are not present, good results for all components will be obtained when a large fraction of the residue pulse-height distribution still remains. In the example given above, for instance, when only two passes have been made for each radionuclide, or 77 percent of the total activity removed, the error for the Tl^{44} = 4.5 %, Cs^{134} = 15 % and Y^{88} = 7.5 %. When minor components are present, similar results can be expected when two passes have been made for each radionuclide.

(5) This computer program should do well for radionuclides having gamma photopeaks very close to one another as, for example, Zr^{95} and Nb^{95}, Ce^{141} and Ce^{144}, and Ru^{103} and Ru^{106}. Advantage can be taken of the fact that operations are being performed on the pulse-height

distribution that are constantly changing its shape. For example, in an equilibrium mixture of Zr^{95} and Nb^{95}, the peak at 0.74 Mev might be identified as either all Zr^{95} (0.72 Mev), or Nb^{95} (0.76 Mev). Subtraction of 10 percent of the peak with the Zr^{95} standard would produce a larger shift in the energy of the resulting peak than a 10 percent subtraction of Nb^{95}. This is because there is more of the Nb^{95} photon in the equilibrium mixture. Therefore, the program, after trying both subtractions, would recognize this smaller shift in energy and the Nb^{95} would be subtracted. The remainder of the peak would be reduced in a similar manner. (The 50 percent peak subtractions for each pass in the example given above are this large so that the number of plots needed in the development of the program would not be too large. A much smaller percentage subtraction will be used in the final computer program.)

(6) Another advantage of this computer program is that very complex mixtures of radionuclides do not make the analysis much more difficult. As long as one photopeak can be identified, the other ill-defined portions of the pulse-height distribution composed of other photopeaks of the same radionuclide, compton edges, etc. will become better defined since the components containing these masking details are partially removed. For example, large amounts of Te^{132}-I^{132} in a complex mixture could completely mask a small amount of Cs^{137}. As the Te^{132}-I^{132} was removed, the Cs^{137} would become better defined. By the

time the Te^{132} photopeak was smaller than that of the Cs^{137}, the interfering peak of the I^{132} would be less than 10 percent of the Cs^{137} photopeak.

(7) This method is not very sensitive to gain and baseline shifts of the detector. The only limiting factor is that the shift is not larger than the range of channels ($\pm$ 20 in the present development) chosen for peak identification.

Many refinements may be made in this computer program for analyzing mixtures of radionuclides. This method of analysis will make possible the determination of very large numbers of low activity samples that are a necessary part of the study of the identification of the chemical and physical species of underwater nuclear explosion debris.

APPENDIX I

Computer Program for Identifying Components in a Mixture of Gamma-Emitting Radionuclides.

```
*       XEQ
*       SYMTBL
*       FORTRAN
C THIS IS A STRIPPING PROGRAM FOR GAMMA SPECTRA
      DIMENSION ST( 9,1032),UNK(1032), BUFFER(1000), WTUNK(1032)
      DIMENSION STD(2000)
      NTHTRY = 0
      READ 100,NUMBST
  100 FORMAT (I1)
      DO 3 I = 1, NUMBST
      CALL REBIN (1024,STD)
      DO 4 J = 1,1024
    4 ST(I,J) = STD (J)
    3 CONTINUE
      CALL REBIN (1024,UNK)
      CALL DREXEL (UNK,NTHTRY)
      DO 9 LEE = 10, 1032
      XLEE = LEE
      FUDGE = 2.0
    9 WTUNK(LEE) = SQRTF(XLEE )/FUDGE
      SIGUNK=0.0
      DO 10 LOVE = 10,1032
   10 SIGUNK=SIGUNK + UNK(LOVE)
   11 DO 12 JIM =10,1032
      ARNIE = 0.0
   12 ARNIE =ARNIE + UNK(JIM)
      IF(SIGUNK/ARNIE - 25.) 13,13,14
   13 CALL PEAK1( JUNK, UNK, WTUNK)
      CALL PEAKST (JUNK, LST, IP, ST, UNK, NUMBST, NTHTRY)
      CALL BRISS (LST, JUNK, IP, ST, UNK)
      CALL DREXEL ( UNK,NTHTRY)
      GO TO 11
   14 CALL STOPLT
      CALL EXIT
      END (0,1,0,0,0)

      SUBROUTINE REBIN (NCHANL, WD)
      DIMENSION WD(1), STOA(12), STOB(12)
      NCARD = (NCHANL + 31) / 12
      DO 50 IA = 1, NCARD
      IB = 12 * IA + 1
S     RCD
      DO 10 IC = 1, 12
S     CPY STOA(IC)
S     CPY STOB(IC)
   10 CONTINUE
      KOUNT = 0
      DO 30 IC = 1, 9
      K = 10 - IC
S     CAL STOB(IC)
S     LRS 32
S     TZE*30
S     LRS 3
S     TZE*21
S     STQ STOR
      KOUNT = K * 1000
S     CLM
S     LDQ STOR
S  21 LLS 1
S     TZE*22
S     STQ STOR
      KOUNT = KOUNT + K * 100
S     CLM
```

```
S       LDQ STOR
S    22 LLS 1
S       TZE*23
S       STQ STOR
        KOUNT = KOUNT + K * 10
S       CLM
S       LDQ STOR
S    23 LLS 1
S       TZE*30
        KOUNT = KOUNT + K
    30  CONTINUE
        IF (KOUNT) 60, 60, 31
    31  IF (KOUNT - IA) 40, 41, 40
    40  PRINT 900, IA, KOUNT
    41  DO 50 IC = 1, 12
        ID = IB - IC
S       CLA STOA(IC)
S       FAD STOA(IC)
S       FSB STOA(IC)
S       STO WD(ID)
    50  CONTINUE
    60  IF (IA - NCARD) 61, 70, 70
    61  IB = NCARD - 1
        DO 65 IC = IA, IB
        DO 65 ID = 1, 12
        IE = 12 * IC + ID - 12
    65  WD(IE) = 0.0
    70  RETURN
   900  FORMAT (5HOCARD I5, 33H IS OUT OF ORDER, CURRENT CARD IS  I5, 19H
       1- DATA IS ACCEPTED  ///)
        END (0,0,0,0,0)


*       FORTRAN
        SUBROUTINE DREXEL (UNK,NTHTRY)
        DIMENSION SP(1032), TITLE(16), BUFFER(1000),UNK(1032)
        IF (NTHTRY) 111,111,112
   111  CALL PLOTS(BUFFER(1000),1000)
C       LOCATE THE PEN AT THE ORIGIN WITH COORDINATES (0.0,0.0)
   112  CALL PLOT( 5., 11., -3 )
        CALL PLOT( 0.0, -10.375,  -3 )
        NOCHAN = 1024
        NODCDS=4
        XSL=10.24
        DCDL=2.4
        ORMEV =0.0
        DXMEV=.1
        KEY = 0
        INITIA =10
        NOSP =1
        LAST =1024
     3  CALL PLOT (-2.44, 2.4, 3)
        CALL PLOT (-2.44, 7.25, 2)
C       THE FOLLOWING DO LOOP IS TO PREVENT UNK GETTING CLOBBERED
        DO 2 I=1,1024
     2  SP(I) = UNK(I)
C       DEFINITIONS OF ARGUMENTS  FOR SUBROUTINES
    10  DELTA = XSL/ FLOATF(NOCHAN )
        XSTART= FLOATF( INITIA - 1 )* DELTA
        YSL   =  DCDL * FLOATF( NODCDS )
        YLEG  = YSL - .9
        IFINAL = LAST - INITIA + 1
        DO  50 N=1,NOSP
```

```
      CALL INPUT (KEY,NOCHAN,SP,TITLE)
      IF( N - 1 ) 20, 20, 40
C     FIND THE MAXIMUM  VALUE TO BE PLOTTED
   20 CALL LARGC( YMAX, INITIA, LAST, SP )
C     SNOTN  SPLITS A NUMBER INTO SCIENTIFIC NOTATION
      CALL SNOTN( YMAX, S, E )
C     INDCD IS THE  EXPONENT OF THE   FIRST DECADE
      INDCD =  XINTF(E) + 1 - NODCDS
C     GRID DRAWS THE SEMI-LOG  GRID FOR PLOTTING THE SPECTRA
      CALL GRID( XSL,DCDL,NOCHAN,NODCDS,INDCD,ORMEV,DXMEV )
C     SEMLGS  SCALES THE SPECTRA TO MATCH THE GRID
   40 CALL SEMLGS(0.,DCDL,INDCD,INITIA,LAST, SP )
C     HISTGM PLOTS THE SPECTRA
      CALL HISTGM( XSTART, 0.0, DELTA, 1, IFINAL,  SP )
C     LEGEND  PRINTS THE IDENTIFICATION OF THE SPECTRA ON THE PLOT
      CALL LEGEND(XSL+.5, YLEG, TITLE  )
   50 YLEG =YLEG -1.25
C      SET UP THE ORIGIN FOR THE NEXT PLOT
      CALL PLOT( XSL + 6.75, 0.0, -3 )
      RETURN
  100 FORMAT( 4I5, 4F10.0 )
      END(0,1,0,0,0)


      SUBROUTINE PEAK1(JUNK,UNK,WTUNK)
      DIMENSION UNK(1032),WTUNK(1032)
      BIGUNK = UNK(150)
      DO 113 I= 151,1001
      IF (I-1000)111,111,114
  111 IF(BIGUNK-UNK(I))112,113,113
  112 BIGUNK = UNK(I)
      JUNK = I
  113 CONTINUE
  114 RETURN
      END (0,1,0,0,0)

*     FORTRAN
      SUBROUTINE PEAKST(JUNK,LST,I ,ST,UNK,NUMBST, NTHTRY)
      DIMENSION  ST(9,1032)
      NTHTRY = NTHTRY + 1
      J = NUMBST + 1
      IF ( NTHTRY - 60 ) 5,80,80
    5 DO 60 I = 1,J
      IPASS = 0
      IF ( I - NUMBST ) 10,10,80
   10 BIGST = ST ( I, 150 )
      DO 15 K = 151, 1001
      IF ( BIGST - ST ( I, K ) ) 12, 15, 15
   12 BIGST = ST (I,K)
      LST = K
   15 CONTINUE
      L2 = LST + 50
      BIGST = ST ( I , L2)
      DO 20 K2 = L2,1001
      IF ( BIGST - ST (I, K2)) 16, 20, 20
   16 BIGST = ST ( I, K2)
      MST = K2
   20 CONTINUE
      CALL OPCON (2,6,5)
      PRINT 82 , ST(I,2),LST,MST,JUNK
   82 FORMAT(9X,8HSTANDARD,F9.0,7HHIGH PK,I9,6HLOW PK,I9,9X,4HJUNK,I9)
   24 DO 30 NP = 1,40
      IF (JUNK-LST-20 + NP) 30,40,30
```

```
 30 CONTINUE
    IPASS = IPASS + 1
 33 DO 35 JP = 1,40
    IF (JUNK-MST-20 + JP ) 35,40,35
 35 CONTINUE
 60 CONTINUE
 40 PRINT 41 , ST(I,2),JUNK, LST, MST
 41 FORMAT(9X,23HPEAKCOMPARISON FND,ST=,F5.0,5HJUNK=,I5,4HLST=,I5,I5,)
    IF (IPASS ) 70,70,69
 69 LST = MST
 70 RETURN
 80 PRINT 81, NTHTRY
 81 FORMAT(9X,33HNO PEAK COMPARISON FOUND NTHTRY =,I5)
    CALL NOPCON
    CALL STOPLT
    CALL EXIT
    END ( 0,1,0,0,0)

    SUBROUTINE BRISS (LST,JUNK,I ,ST,UNK)
    DIMENSION UNK (1032), ST(9,1032),TAKOPH(1032)
    IB =LST-5
    JB =LST+5
    SUMUNK=0.0
    SUMST=0.0
    DO 145 KB =  IB,JB
    SUMUNK =SUMUNK + UNK(KB)
145 SUMST = SUMST + ST(I ,KB)
    FACTOR = SUMUNK/(2.*SUMST)
    DO 146 LB=10,1032
    TAKOPH (LB) =FACTOR*ST(I ,LB)
146 UNK(LB) = UNK(LB) - TAKOPH(LB)
    CONTINUE
    RETURN
    END (0,1,0,0,0)

    SUBROUTINE INPUT(KEY, NOCHAN,SP, TITLE)
    DIMENSION SP( 1032 ), TITLE( 16 )
    N = NOCHAN + 8
 40 TITLE(1) = SP(2)
    TITLE(2) = SP(3)
    TITLE(3)= 1960. +  MODF( SP(4)*.001 ,10. )
    TITLE(4)= .001*SP(5) + MODF( SP(4) , 1000. )
    TITLE(5)=SP(1) * .1
    IF( KEY ) 50, 60, 70
 50 TITLE(6) = 1000.*SP(6) + SP(7)
    DO 55 I = 1,256
 55 SP(I) = SP( I + 8 )
    GO TO 80
 60 TITLE(6) = 0.0
    DO 65 I = 9,NOCHAN
 65 TITLE(6) = TITLE(6) + SP(I)
    GO TO 80
 70 TITLE(6) = SP(KEY )
 80 CALL SNOTN( TITLE(6), TITLE(7), TITLE(8) )
    RETURN
100 FORMAT( 14F5.0, 2X )
    END(0,1,0,0,0)
```

```
                SUBROUTINE LARGE COMPONENT  FINDS THE LARGEST COMPONENT OF A

C     VECTOR BETWEEN THE I AND L COMPONENTS
C
      SUBROUTINE  LARGC( C, I, L, V )
C
C     C   IS THE LARGEST COMPONENT
C     I  IS THE FIRST COMPONENT  CHECKED
C     L IS THE LAST COMPONENT CHECKED
C     V IS THE NAME OF THE VECTOR
C
      DIMENSION V(1)
      C = V(I)
      DO 20 K = I,L
      IF( V(K) - C ) 20, 20, 10
   10 C = V(K)
   20 CONTINUE
      RETURN
      END(0,0,0,0,0)


      SUBROUTINE GRID (XSL, DCDL, NOCHAN, NODCDS, INDCD ,ORMEV, DXMEV )
C
C     XSL IS THE LENGTH OF THE X AXIS                ( INCHES )
C     DCDL IS THE LENGTH OF A DECADE                 ( INCHES )
C     NOCHAN IS THE NUMBER OF CHANNELS
C     NODCDS IS THE NUMBER OF DECADES
C     INDCD IS THE EXPONENT OF THE VALUE OF THE Y ORIGIN
C
C     DRAW TEAR LINE
      CALL PLOT (-2.44, 2.4, 3)
      CALL PLOT (-2.44, 7.25, 2)
C
      DELTA = 10.* XSL / FLOATF( NOCHAN )
      YSL = DCDL * FLOATF( NODCDS )
      IF( INDCD + NODCDS ) 5,5,10
    5 CALL SYMBL4(-.75,4.3,.21,5HK (I), 90.,5 )
      GO TO  15
   10 CALL SYMBL4(-.75,4.3,.21,5HA (I), 90.,5 )
C
C     LAXIS DRAWS  VERTICAL LOG SCALES TO FORM SEMI-LOG GRIDS
   15 CALL LAXIS( 0.,0.,XSL,DCDL,.05,NODCDS,INDCD )
C
C     PHAXIS DRAWS AND LABELS THE SCALE ON THE X AXIS
      CALL PHAXIS( 0.0 ,0., XSL ,DELTA,  .05 , .0001 , 50., -1 )
C
      CALL SYMBL4 ( 4.1,-.5,.21,10HCHANNEL, I ,0., 10 )
C
      CALL PHAXIS( 0.0, YSL, XSL,DELTA, -.05, ORMEV, DXMEV, 2 )
      IF( DXMEV ) 20, 25, 20
   20 CALL SYMBL4(  4., YSL+.5 , .21,12HENERGY (MEV) , 0.0, 12 )
   25 CALL SYMBL4(XSL+.5, 9.25,.21,12HU.S.N.R.D.L., 0.,12)
      RETURN
      END(0,0,0,0,0)
```

```
      SUBROUTINE  HISTGM( X, Y, DELTA, INITIA, LAST, YH )
C
C     X IS THE X COORDINATE OF THE  FIRST POINT              ( INCHES )
C     Y IS THE  LOCATION OF THE Y COORDINATE OF THE ORIGIN   ( INCHES )
C     DELTA IS THE DISTANCE BETWEEN  POINTS                  ( INCHES )
C     INITIA IS THE FIRST COMPONENT PLOTTED
C     LAST IS THE LAST COMPONENT PLOTTED
C     YH IS THE VECTOR
C
      DIMENSION YH(1)
      CALL PLOT( X, Y, 3 )
      XH1 =  X
C
C     IF DELTA IS VERY SMALL  THE HISTOGRAM  BECOMES  A PT. TO PT. PLOT
      IF( DELTA - .02 )   15,15,5
    5 DO  10 I = INITIA , LAST
      CALL PLOT(  XH1,YH(I) , 2 )
C
C     INCREMENT THE  X VALUE
      XH1 = XH1 + DELTA
   10 CALL PLOT(  XH1,YH(I) , 2 )
      GO TO 25
   15 DO 20 I = INITIA,LAST
      CALL PLOT(  XH1,YH(I) , 2 )
C
C     INCREMENT THE X VALUE
   20 XH1 = XH1 + DELTA
   25 CALL PLOT( XH1, Y, 2 )
      RETURN
      END (0,0,0,0,0)

                  LAXIS DRAWS A VERTICAL LOG AXIS

C     X AND Y ARE THE COORDINATES OF THE  OF THE GRID        ( INCHES )
C     XSL IS THE LENGTH OF THE  X AXIS                       ( INCHES )
C     DCDL IS THE LENGTH OF A DECADE                         ( INCHES )
C     TICL IS THE LENGTH OF THE TIC MARKS                    ( INCHES )
C     NODCDS IS THE NUMBER OF DECADES DESIRED
C     INDCD IS THE EXPONENT OF THE INITIAL DECADE
      SUBROUTINE LAXIS(X,Y,XSL,DCDL,TICL,NODCDS,INDCD )
      DIMENSION  DY(10)
      XE    = X - .63
      YE    = Y - .11
      XEE   = X-  .21
      YEE   = Y + .06
      INDEX =  INDCD
      XX    = X- TICL
      XSL   = X+XSL
      XXX   = XSL+ TICL
      L     = NODCDS + 1
C
C     COMPUTE  VERTICAL INCREMENTS WITHIN  DECADES
      DO   5     J=    2,10
    5 DY(J) = DCDL * LOG10F( FLOATF(J) )
      CALL PLOT(X,Y,3)
C     DRAW LEFT  AXIS   AND DECADE LINES
      YD = Y
      DO   15    J = 1,NODCDS
      DO   10    K= 2, 10
      YY = YD + DY( K)
      CALL PLOT ( X, YY,2)
```

```
      CALL PLOT ( XX,YY,2)
   10 CALL PLOT (X,  YY,2)
      CALL PLOT (XSL,YY,2)
      CALL PLOT (X,  YY,2)
   15 YD = YD + DCDL
C     DRAW  VERTICAL  LABELS
      DO   20  J = 1, L
      CALL NUMBER (XE ,YE ,.21,10.,0., -1)
      EX = FLOATF( INDEX )
      CALL NUMBER (XEE,YEE,.07,EX ,0., -1)
      INDEX = INDEX + 1
      YE=  YE + DCDL
   20 YEE= YEE+ DCDL
C     DRAW  RIGHT  AXIS
      CALL PLOT (XSL, Y, 3 )
      YD = Y
      DO   30    J = 1,NODCDS
      DO   25    K=  2,10
      YY = YD + DY( K)
      CALL PLOT (XSL, YY, 2)
      CALL PLOT (XXX, YY, 2)
   25 CALL PLOT (XSL, YY, 2)
   30 YD = YD + DCDL
      CALL PLOT ( X,Y,3)
      RETURN
      END (0,0,0,0,0)

      SUBROUTINE LEGEND( X, YLEG, TITLE )
      DIMENSION TITLE(16)
      Y = YLEG
      XP   = X + 1.
      XT   = X + 2.75
      GC = TITLE(6)
      CALL SYMBL4 ( X,Y, .14,  18HSAMPLE          CODE,    0., 18  )
      CALL NUMBER (XP,Y, .14, TITLE(1), 0., -1 )
      CALL NUMBER (XT,Y, .14, TITLE(2), 0., -1 )
      Y=  Y- .25
      CALL SYMBL4 (X ,Y, .14,  17HYEAR            DAY,     0., 17  )
      CALL NUMBER (XP,Y, .14, TITLE(3), 0., -1 )
      CALL NUMBER (XT,Y, .14, TITLE(4), 0.,  3 )
      Y=   Y- .25
      CALL SYMBL4 ( X,Y, .14,  17HCOUNTING INTERVAL,     0., 17  )
      CALL NUMBER (XT,Y, .14, TITLE(5), 0.,  1 )
      Y =  Y -.25
      CALL SYMBL4 ( X,Y, .14,  26HGROSS COUNT             X10 ,0.,26)
      CALL NUMBER (X+1.75,Y,.14,TITLE(7), 0., 6 )
      CALL NUMBER( XT+.75, Y+.07, .07,TITLE(8), 0., -1 )
      RETURN
      END (0,0,0,0,0)

                  PRETTY HORIZONTAL AXIS

C     X AND Y ARE THE COORDINATES OF THE ORIGIN       ( INCHES )
C     XSL IS THE LENGTH OF THE AXIS       ( INCHES )
C     DELTA IS THE DISTANCE BETWEEN THE TIC MARKS     ( INCHES )
C     TIC IS THE LENGTH OF THE SHORT TIC MARKS    ( INCHES )
C     ORCHAN IS THE  BASE VALUE FOR COMPUTING THE LABELS
C     DX IS ADDED TO ORCHAN AT EVERY LONG TIC  AND THE SUM DRAWN
C     N IS THE N USED IN SUBROUTINE NUMBER OF THE CAL COMP SERIES
C
```

```
      SUBROUTINE PHAXIS( X, Y, XSL, DELTA, TIC, ORCHAN, DX, N )
      XA  = X
      CHAN = ORCHAN
      YT = Y -  TIC
      DT = TIC + TIC
      ATIC =  ABSF ( DT )
      NOLAB = XINTF( .2*XSL/DELTA + .001 )
      CLAB = 1.3 * ATIC
      YDT = Y - DT
      YLAB = YDT - DT
C
C     START PEN AT ORIGIN
      CALL PLOT ( XA , Y  , 3  )
C
      DO  20  K  =  1 , NOLAB
      DO  10  J = 1 , 4
      XA   = XA + DELTA
C
C     MAKE  FOUR SHORT TICS
      CALL PLOT ( XA , Y   , 2  )
      CALL PLOT ( XA , YT  , 2  )
   10 CALL PLOT ( XA , Y   , 2  )
C
C     MAKE AND LABEL  LONG TICS
      XA   = XA + DELTA
      CHAN = CHAN + DX
      XLAB = XA - CLAB
      CALL PLOT ( XA , Y   , 2  )
      CALL PLOT ( XA , YDT , 2  )
      IF( DX ) 15,20,15
   15 CALL NUMBER ( XLAB , YLAB ,ATIC, CHAN  ,  0.0 ,  N  )
   20 CALL PLOT ( XA , Y  , 3  )
      CALL PLOT ( XSL , Y  , 2 )
C
      RETURN
      END (0,0,0,0,0)

      SUBROUTINE SEMLGS ( Y, DCDL, INDCD, INV, LASTV,V)
C     SEMI-LOG SCALE SHIFTS , LOGS, AND SCALES A VECTOR FOR SEMI-LOG PLO
C     Y      IS THE LOCATION OF THE ORIGIN                    ( INCHES )
C     DCDL   IS THE LENGTH OF A DECADE                        ( INCHES )
C     INDCD  IS THE EXPONENT OF THE VALUE OF THE ORIGIN
C     INV    IS THE INITIAL COMPONENT SCALED
C     LASTV  IS THE LAST COMPONENT SCALED
C     V  IS THE VECTOR TO BE SCALED
C
      DIMENSION V(1)
C
      VMIN = 10.**INDCD
      BASE = DCDL * FLOATF( INDCD ) - Y
      J = 1
      SF = .4342945*DCDL
C
C
      DO 20 K = INV, LASTV
C
C     THE  IF STATEMENT AVOIDS  UNDEFINED OR UNPLOTTABLE  VALUES
      IF( V(K) - VMIN ) 10, 10,15
   10 V(J) = Y
      GO TO 20
C
   15 V(J) = SF* LOGF( V(K) ) - BASE
C
   20 J = J+1
      RETURN
      END(0,0,0,0,0)
```

THIS SUBROUTINE WILL FIND THE MAGNITUDE OF A NUMBER

```
C     GIVEN X THE ROUTINE FINDS S AND E SUCH THAT    X = S*10.**E
      SUBROUTINE SNOTN( X, S, E )
      J = 0
      S = ABSF( X )
      IF( S ) 6, 6, 1
    1 IF( 10. - S ) 2, 2, 3
    2 S = S* .1
      J = J + 1
      GO TO 1
    3 IF( S - 1. ) 4, 5, 5
    4 S = S * 10.
      J = J - 1
      GO TO 3
    5 S = SIGNF( S,X )
    6 E = FLOATF( J )
      RETURN
      END (0,0,0,0,0)
```

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13. ABSTRACT

A computer program has been developed for the analysis of the components of a gamma pulse-height distribution composed of a mixture of two or more gamma-emitting radionuclides. The program consists of (1) identifying the largest gamma photopeak and matching its energy with the largest photopeak of each of the individual radionuclides that compose the mixture, (2) subtracting enough of the individual radionuclide gamma pulse-height distribution from the mixture so that the photopeak in question is reduced by a certain small percentage, and (3) continuing the incremental subtraction process until the photopeaks in the mixture can no longer be identified. This computer program has several advantages over other computer programs that have been developed to do the equivalent of a radiochemical analysis on a mixture of radionuclides. It will be especially useful in analyzing the large number of low activity mixtures of radionuclides that are to be made in the program to determine the physical-chemical species of the radionuclide debris produced by underwater nuclear explosions.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Gamma spectra						
Radiochemical analysis						
Activation analysis						